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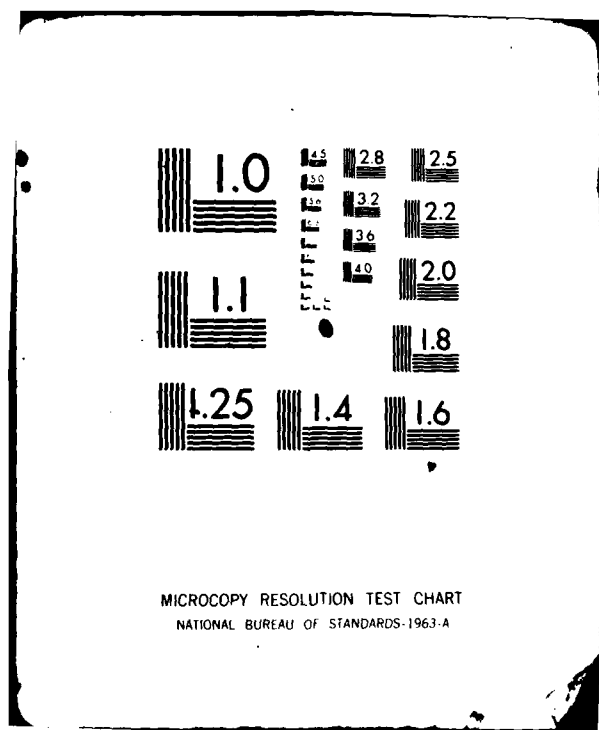
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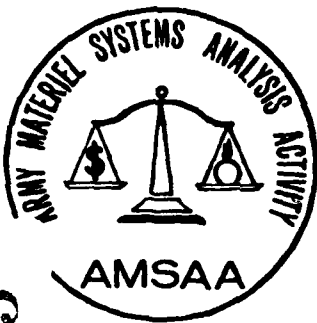
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PRODUCTION RISK

ASSESSING METHODOLOGY (PRAM)

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U.S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
ARMY PROCUREMENT RESEARCH OFFICE
FORT LEE, VIRGINIA 23801

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PRODUCTION RISK
ASSESSING METHODOLOGY (PRAM)

by

Monte Norton

Richard Abeyta

Paul Grover

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The pronouns "he," "his," and "him," when used in this publication represent both the masculine and feminine genders unless otherwise specifically stated.

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US ARMY PROCUREMENT RESEARCH OFFICE
US Army Materiel Systems Analysis Activity
Fort Lee, Virginia 23801

EXECUTIVE SUMMARY

A. BACKGROUND/PROBLEM. The Army is currently moving a significant number of sophisticated weapon systems from R&D to production. This transition process is bringing to light a considerable amount of production cost growth. Initial production uncertainties need to be analyzed and contingencies addressed to avoid or to minimize program disruptions. An approach similar to the one used to address R&D uncertainties, TRACE, appears feasible to analyze the early production risks and to account for them in the program plan.

B. STUDY OBJECTIVES. The study objectives are to identify the causes of transition problems and to develop a production risk assessing methodology which addresses and quantifies initial production uncertainties.

C. STUDY APPROACH. Research began with a review of pertinent literature and current policy regarding production planning and budgeting. TRACE and similar techniques were reviewed for application potential. Selected Major Subordinate Commands and Project Management Offices within the US Army Materiel Development and Readiness Command and contractors with recent experience in moving from R&D to production were visited to gain insights into problem areas. A methodology was then developed to address production uncertainties.

D. CONCLUSIONS AND RECOMMENDATIONS. By analyzing Army SAR systems during the transition from R&D to production, it was determined that a 35% average cost growth was occurring in the Procurement appropriation (excluding inflation and quantity changes) which amounts to over \$5 billion. It was also determined that, as in R&D, risks are inherent in all systems during early production and often lead to large production cost increases. The various techniques used to address risk and uncertainty, including those used in the Army's TRACE program, were reviewed. Although these same techniques can be used to address initial production risks, the Production Risk Assessing Methodology (PRAM) offers an improvement. It combines an empirically developed risk structure with conventional cost estimating techniques to quantify initial production risks into a dollar estimate which complements the Baseline Cost Estimate. Using the PRAM, production risk and cost growth can be reduced. However, PRAM should first be appropriately tested. Following successful testing, it should be incorporated on Army major weapon systems.

E. IMPLEMENTATION. PRAM has been tested and, with some modifications, incorporated into a methodology titled Total Risk Assessment Cost Estimating for Production (TRACE/P). As an approved DARCOM methodology, TRACE/P is being applied where appropriate to develop cost estimates which include consideration for initial production risk.

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CHAPTER I

INTRODUCTION

A. BACKGROUND/PROBLEM.

The Army is currently moving a significant number of sophisticated weapon systems from Research and Development (R&D) to production. This transition process is surfacing a considerable number of production problems. Some of the problems are anticipated, but many others are not. These unexpected problems usually result in undesirable funding adjustments and what is perceived as program cost growth.

The reasons for the difficulties and attendant cost growth are many and varied. Sometimes the problems are beyond the control of those responsible for managing the system; nonetheless, they occur regularly. A methodology is needed to analyze the uncertainties of entering production and to account for the risk impacts in the program plan. By planning and budgeting for initial production risks, program disruptions and costs can be minimized.

Two recent memorandums within DOD have recognized this problem and initiated efforts for improvement. They are DEPSECDEF Memorandum, 30 Apr 81, subject: Improving the Acquisition Process (Recommendations 6 and 11) and the VCS, Army Memorandum, 22 Jul 81, subject: Cost Discipline.

One technique currently accepted by Congress and used to address uncertainties in R&D is the Total Risk Assessing Cost Estimate (TRACE). This technique assesses technical, cost, and schedule risks and establishes a TRACE deferral (funds budgeted for uncertain activities) that is available for the Project Manager (PM) to draw upon when justified.

The DARCOM MSC's and PMO's visited to gain an understanding of typical early production problems are:

1. US Army Aviation Research & Development Command (AVRADCOM)
 - a. CH-47 Mod
 - b. Remotely Piloted Vehicle (RPV)
 - c. Advanced Attack Helicopter (AAH)
 - d. Blackhawk
2. US Army Missile Command (MICOM)
 - a. Stinger
 - b. Pershing II
 - c. Roland
 - d. Patriot
3. US Army Tank-Automotive Command (TACOM)
 - a. Abrams Tank (M1)
 - b. Fighting Vehicle System (FVS)

The defense contractors visited are:

1. Chrysler
Lima Army Tank Plant
Lima, Ohio
2. Food and Machinery Corporation (FMC)
San Jose, California
3. General Dynamics
Pomona, California

Additional government organizations involved in transition related activities were also visited to gain insights into initial production problems and uncertainties.

D. REPORT ORGANIZATION.

Chapter II describes the transition period and recent transition problems and cost growth experience within the Army. The techniques currently available to assess program risk are discussed in Chapter III, and Chapter IV presents a specifically designed methodology for assessing initial production risk. Chapter V states the study conclusions and implementation recommendations.

CHAPTER II

TRANSITION FROM DEVELOPMENT TO PRODUCTION

A. INTRODUCTION.

A key milestone in the life cycle of an Army weapon system is the decision to enter production. Milestone III, the production decision point, occurs years after concept exploration begins, but only a small percentage of the total expected program life cycle cost has been incurred up to this point. Most of the program funds remain to be expended during the Production/Deployment Phase following Milestone III. Typically, R&D accounts for approximately 15% of the program cost, production 30%, and operation and support the remaining 55%.[3] Therefore, it is prudent that the risks of entering production be understood as clearly as possible before the program is committed further.

This study focuses on the uncertainties and problems experienced during the transition period from development to production. It begins with those activities and events occurring perhaps two or three years before Milestone III and extends to the state of routine production. Although there is no commonly accepted definition of this transition period, it is depicted in Figure 2.1 as the shaded area with Milestone III roughly in the middle.[20]

The Army attempts to manage and to prepare for eventual production through many activities, some starting early in the life cycle. The study bibliography contains references which describe these activities and the system life cycle of which the transition period is a part. They are not

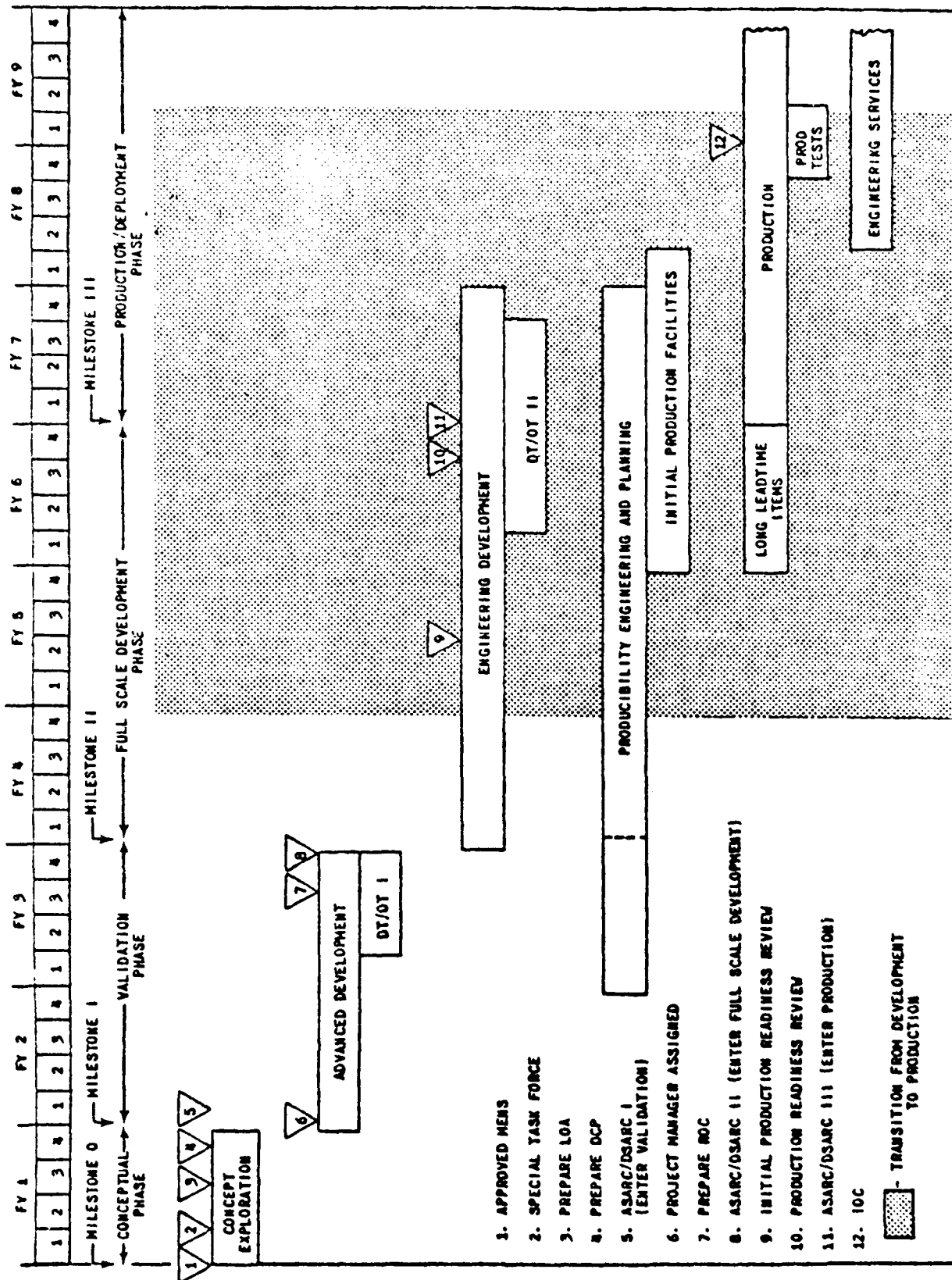


FIGURE 2.1 ACQUISITION PROCESS FOR ARMY MAJOR WEAPON SYSTEMS
(SOURCE: GUIDE FOR TRANSITIONING ARMY MISSILE SYSTEMS FROM
DEVELOPMENT TO PRODUCTION)

repeated here except to mention two of the most effective and well known:

(a) Producibility Engineering and Planning (PEP), and (b) Production Readiness Reviews (PRR). Figure 2.1 shows the relative timing of these activities during the system life cycle.

Both PEP and PRR's are conducted during Full Scale Engineering Development (FSED) to minimize production risks and to ensure a smooth transition from development to production. These activities are described as follows:

1. Producibility Engineering and Planning (PEP).

This element includes cost incurred in assuring the producibility of the developmental weapon system, item, or component. PEP involves the engineering tasks necessary to insure timely, efficient and economic production of essential material and is primarily software in nature. PEP includes efforts related to development of the Technical Data Package (TDP), Quality Assurance (QA) plans, and special production processes to assess producibility. Also included are development of unique processes essential to the design and manufacture of the materiel and details of performance ratings, dimensional and tolerance data, manufacturing assembly, sequences, schematics, mechanical and electrical connections, physical characteristics including form, fit and finishes, inspection test and evaluation requirements, calibration information, and quality control procedures.[9]

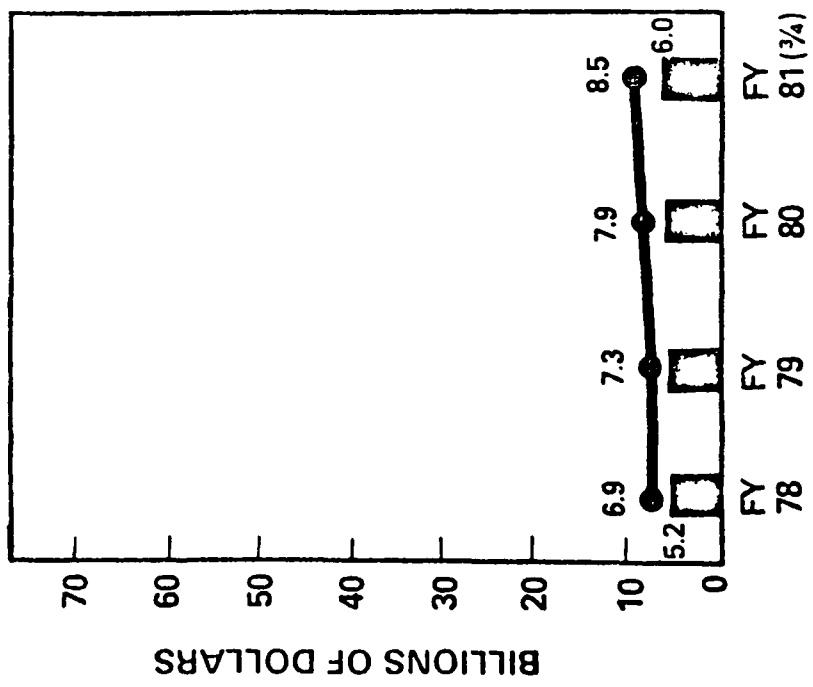
2. Production Readiness Review (PRR).

A formal, documented, systematic review of a program to find: (a) If the system design is ready for production; (b) Production engineering problems have been identified and solutions are in progress; (c) Quality assurance and acceptance test procedures are adequate; and (4) The Army and producer have adequately planned for the production phase.[8]

In spite of the Army's efforts to prepare for production and to control system cost, a weapon system typically experiences problems during this transition period which eventually contribute to substantial increases in program cost. Figure 2.2 shows the extent and alarming trend of the total

THE PRIMARY DRIVER
IN COST GROWTH IS
IN THE PROCUREMENT
APPROPRIATION

23% INCREASE
RDTE



92% INCREASE
PROCUREMENT

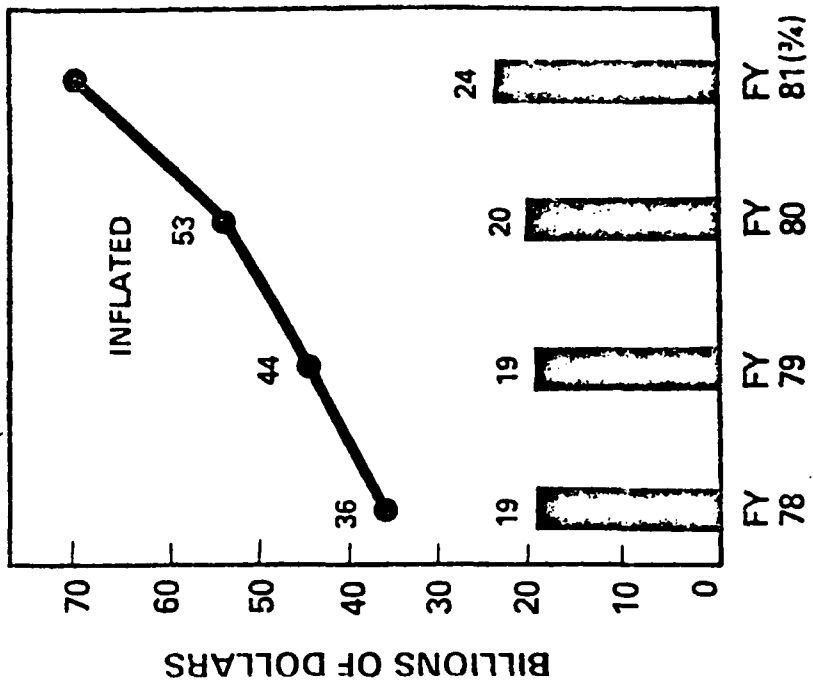


FIGURE 2.2 ARMY WEAPON SYSTEM COST GROWTH
(SOURCE: STUDY OF ARMY LOGISTICS, 1981, AND ARMY SAR'S)

increase in RDT&E and Procurement appropriations for Army systems reported in the Selected Acquisition Report (SAR).[34] Excluding inflation, there still has been a 26% increase in the procurement appropriation from the first quarter of FY 78 through the third quarter of FY 81 compared to 15% increase in RDT&E during the same period.

Design uncertainties and R&D problems are well recognized. Production uncertainties and problems were not as well recognized until recently, but they are similar and have a much larger risk impact on program cost. Figure 2.2 shows the effect both as a percentage increase and in absolute dollars. Also, in a review of the cost growth during the 1970's of 31 DOD systems, RAND found that most of the systems that had passed DSARC III (i.e., Milestone III) exhibited growth in both the development and production phase.[13] The need for more attention to production and for better planning and control of initial production uncertainties is clear.

B. GENERAL COST GROWTH.

Much has been written about the causes of cost growth throughout the life cycle of a weapon system. The Institute for Defense Analyses (IDA) summarized some of the more frequently cited causes of cost growth as follows:[1]

"Force Majeure"

- Natural disaster
- Civil disorder
- Labor strike
- Fire

General Economic Inflation

Cost estimates based on previous similar system (each succeeding generation tends to cost more than last generation).

Supply shortages

Labor shortages

Poor management

Technological uncertainty

- Unknowns
- Unknown unknowns

Environmental laws/regulations

Specification changes

Quantity changes

Reliability problems

Concurrency (trying to produce too fast)

Tight budgets

Competitive environment

- within branch of service
- within service
- among services
- DOD vs. other federal agencies
- Executive branch vs. Congress
- among contractors
- among individuals

IDA emphasized that two causes should be singled out because of their impact:

1. The competitive environment in which weapon systems are developed is the major factor leading to cost growth; and
2. Tight budgets are an often overlooked cause of cost growth.

RAND, in an earlier study, examined DOD major weapon systems cost growth. Using the SAR cost variance categories, RAND found that

"The persistence of cost growth after DSARC III can be traced to two principal causes: schedule slip-pages and efforts to increase system performance." [13]

Although DOD may attempt to shift production risk to a defense contractor through the use of firm, fixed price (FFP) contracts, the Army Procurement Research Office (APRO) has shown in earlier work that this has little impact on cost growth. "FFP contracts suffered a net 53% cost growth - almost identical to the entire sample cost growth." [22] Nearly all of the FFP contracts were for production.

In summary, the cost growth literature within the defense community agrees that weapon system costs during R&D and production are increasing for many and varied reasons.

C. TRANSITION COST GROWTH.

The magnitude and trend of transition problems were studied further in terms of budgetary impact. In 1979, Augustine reported that for 38 DOD programs from 1962-1976, program cost growth of 9% occurs after R&D is complete, adjusting for inflation and quantity changes.[2] Factoring out the R&D cost, procurement cost growth for these SAR programs was about 12%.

To evaluate current programs, eleven Army SAR systems that have recently undergone transition from R&D to production were analyzed to determine Procurement cost growth during early production. SAR Procurement cost data in constant dollars was adjusted for quantity changes with a baseline taken at the quarterly SAR three to six months prior to ASARC III. The systems studied and summary results are shown in Table 2.1. The magnitude of growth, averaging 35.5% and totaling over \$5 billion, indicates an unfavorable trend of higher growth in recent years.

To normalize the growth rate to reflect differences in the length of time these systems have been in production, an Average Quarterly Growth Rate was computed based on the equation

$$1 + \text{Total Percentage Growth} = (1 + i)^n$$

where: Total Percentage Growth is the percent increase from the baseline cost,

i is the Average Quarterly Growth Rate, and

n is the number of quarters of SAR data from the baseline.

The Average Quarterly Growth Rate is also shown on Table 2.1.

TABLE 2.1 SELECTED ACQUISITION REPORT DATA PROCUREMENT COSTS
(IN CONSTANT \$ M ADJUSTED FOR QUANTITY CHANGES)

<u>SYSTEM</u>	<u>BASELINE DATE</u>	<u>BASELINE EST</u>	<u>JUNE 1981 EST</u>	<u>TOTAL % CHANGE</u>	<u>AVG OTLY GROWTH RATE</u>
AN-TCC-39	9/79	341.9	364.8	6.7	.9
BLACKHAWK	6/76	1343.5	2109.3	57.0	2.3
CH47-M	6/80	910.8	962.8	5.7	1.4
COPPERHEAD	3/79	674.7	1004.4	48.9	4.5
FVS	3/79	1860.6	3640.7	95.7	7.7
MLRS	12/79	1841	1927.9	4.7	.8
PATRIOT	3/80	1684.4	2451	45.5	7.8
ROLAND	12/78	1261.3	1549.5	22.8	2.1
STINGER	6/77	401.4	849	111.5	4.8
XM-1	12/78	3934.9	4500.1	14.4	1.4
XM-198	9/76	114	107	-6.1	-.3
TOTAL		14368.5	19466.5		
WEIGHTED AVERAGE				35.5	

The causes of cost growth reported in the SAR's are shown in Table 2.2. It indicates "estimating changes" as the primary contributor. However, because of the guidance followed in classifying SAR changes, "estimating changes" include cost growth beyond that which is caused only by optimistic estimates.

Despite the limitations of SAR cost change classifications,[17, 13], recurring patterns can be identified and conclusions can be drawn by observing the timing and cost growth reported in the SAR. By measuring SAR Procurement constant dollar growth, adjusted for quantity changes, from a baseline ($t = 0$ months) from the second SAR prior to ASARC III, the pattern exhibited in Figure 2.3 emerged. Most of the overall 35.5% growth occurs in the first 24 months of the time period considered, with very steep rises between 3 - 9 months (ASARC III time frame) and 18 - 24 months (1 - 1 1/2 years after ASARC III).

Figure 2.4, which measures quarterly growth, shows cost growth occurring in approximately annual cycles with the greatest magnitude in the first two years. Cyclic growth can continue beyond the first two years though, as demonstrated in Figure 2.7. The procurement cost growth in Army systems may be more severe than indicated thus far in Army SAR's since most of the eleven systems have not yet reached production maturity. The timing of reported growth seems to correlate with the updated cost estimates prepared for ASARC III ($t = 6$ months) and the annual contract negotiation and award cycles.

The cost growth pattern exhibited by the aggregate of the eleven systems is not evident when analyzing each individual system.

TABLE 2.2 SAR COST VARIANCE REASONS

<u>CHANGE CAUSE</u>	<u>AMOUNT \$M</u>	<u>PERCENTAGE</u>
ECONOMIC	N/A	N/A
QUANTITY	-482	-10.4
SCHEDULE	398.5	8.6
ENGINEERING	361.9	7.8
SUPPORT	701.8	15.2
ESTIMATING	3635.8	78.8
OTHER	<u>0</u>	<u>0</u>
TOTAL	4616	100

(Source: 11 Army SAR Systems; Time period of 3-6 months prior to ASARC III to June 1981 in Constant \$)

JUNE 1981 SAR

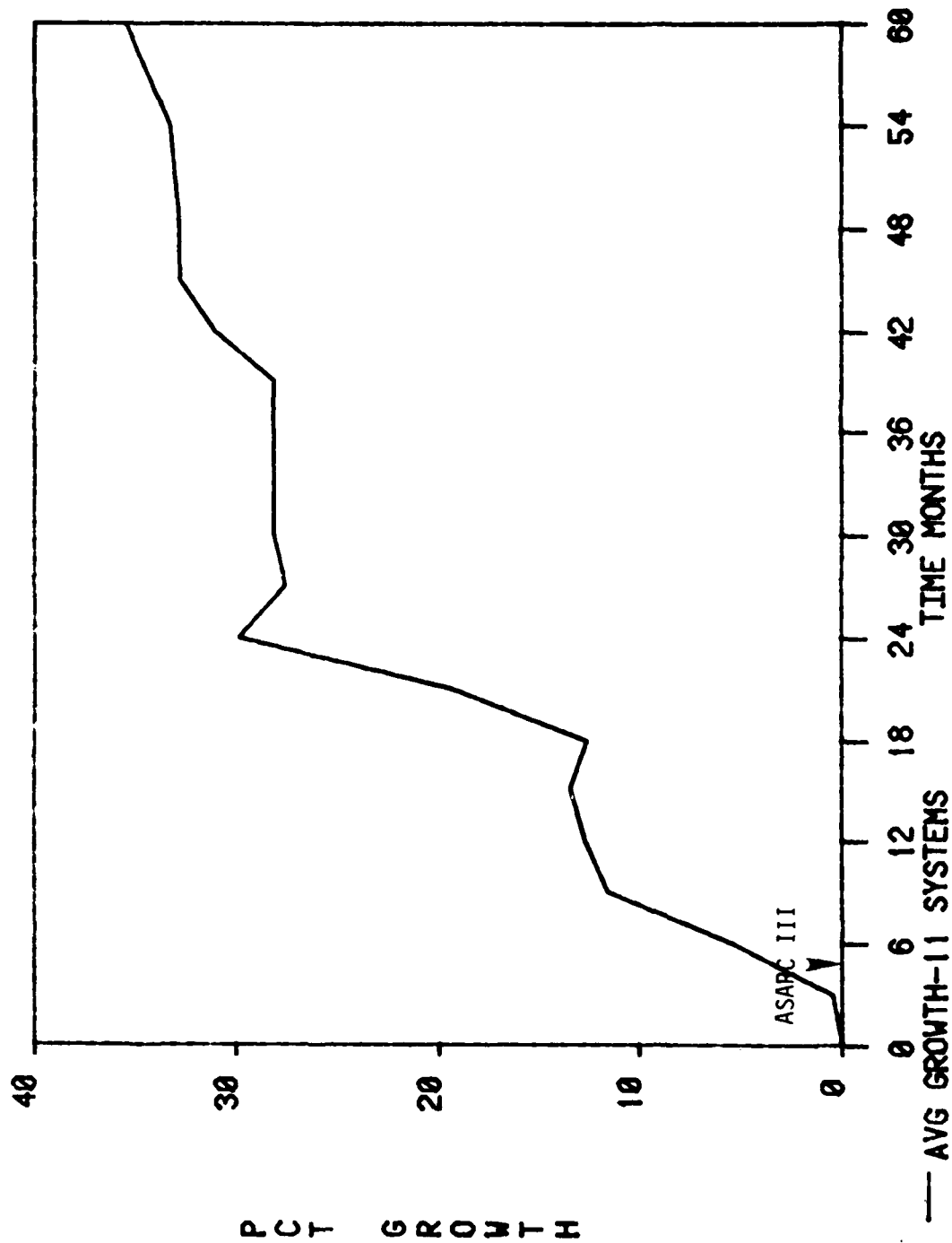


FIGURE 2.3 CUMULATIVE AVERAGE PROCUREMENT COST GROWTH FOR ARMY SAR SYSTEMS

JUNE 1981 SAR

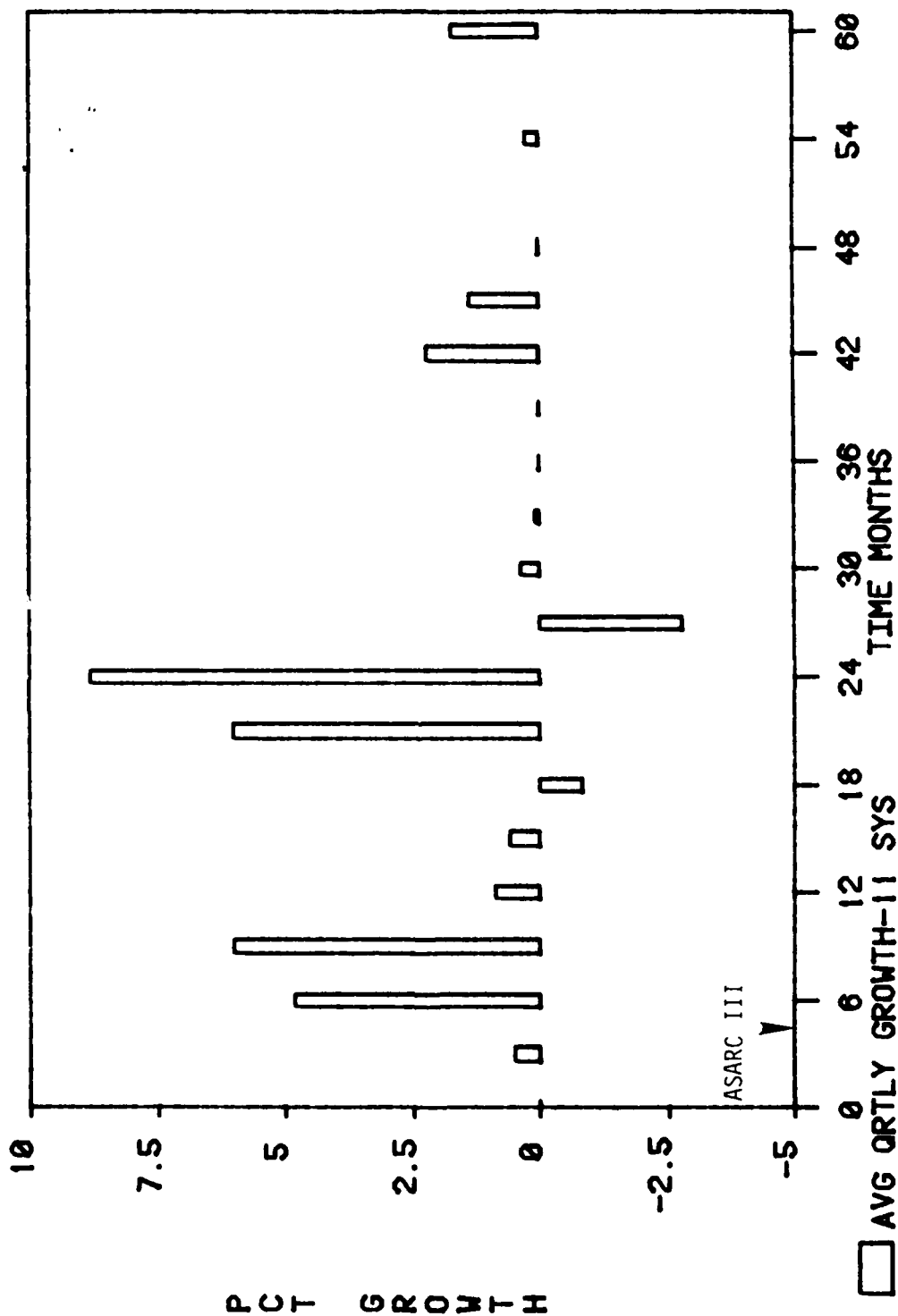


FIGURE 2.4 AVERAGE QUARTERLY PROCUREMENT COST GROWTH FOR ARMY SAR SYSTEMS

Figures 2.5, 2.6, and 2.7 point out that each program has a unique set of problems that are reflected in cost growth patterns of varying degree and periodicity. Some programs grow from the beginning, others delay growth until later in the production cycle, and others have experienced little growth. This is consistent with the notion of uncertainty and probabilistic occurrences. Statistical techniques, although applied to individual programs, are more meaningful on an aggregate basis.

D. TRANSITION PROBLEMS/UNCERTAINTIES.

This study has attempted to identify the fundamental or root causes of production cost growth and to understand the relationships among the various reasons claimed for cost growth in the systems reviewed. Production problems and their reported reasons may not reflect the root cause of cost growth. Rather than being truly isolated, many of the reasons offered can be thought of as part of a chain which starts somewhere (i.e., the root cause) and eventually leads to cost growth. Production problems that are not root causes are merely precipitates of the root cause; although the problems may truly reflect root causes in other paths at other times.

For example, PMO and contractor personnel cited many different reasons for transition cost growth, and not all were root causes. The following are representative of the frequently cited reasons for transition problems:

JUNE 1981 SAR

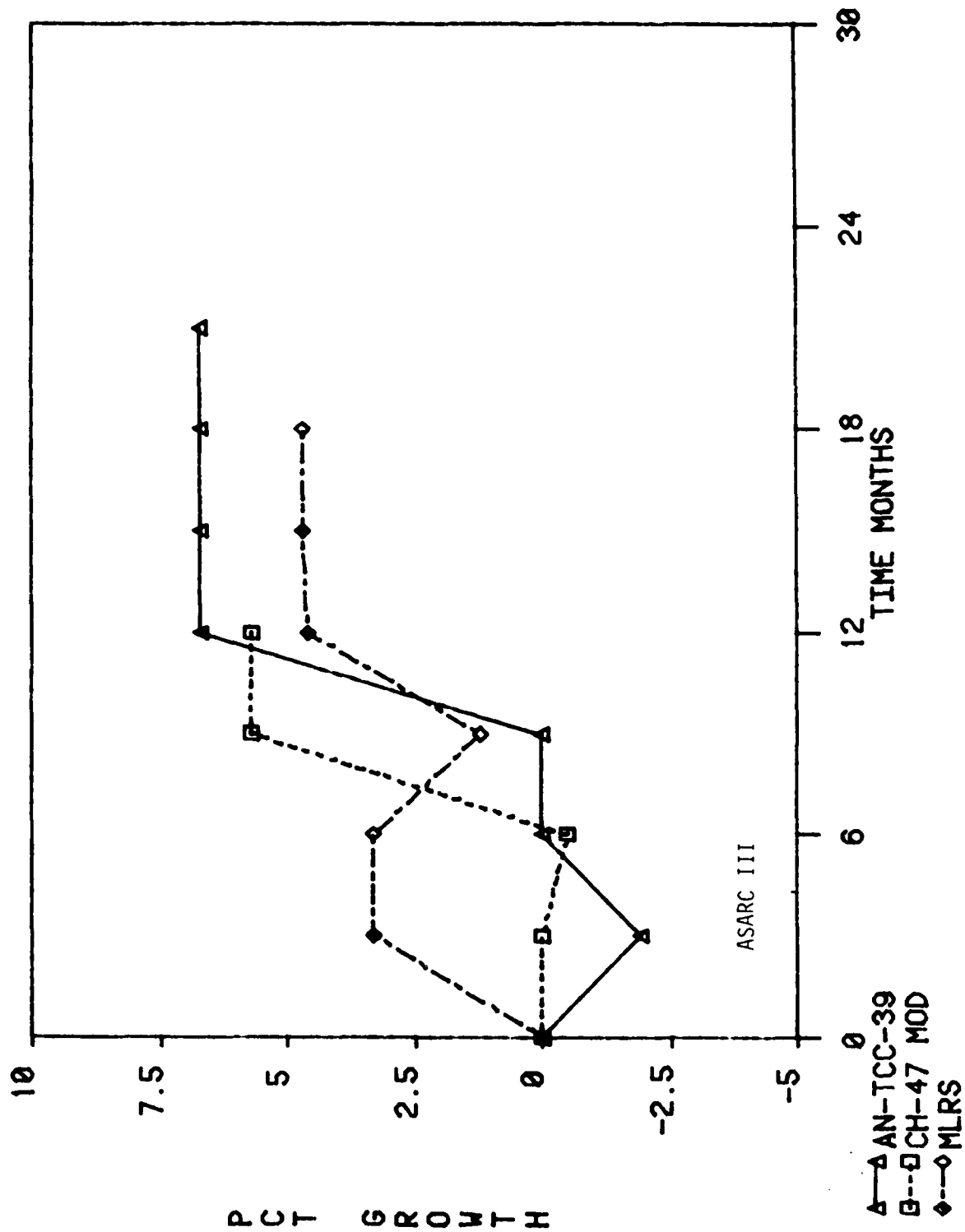


FIGURE 2.5 CUMULATIVE PROCUREMENT COST GROWTH (1)
(SOURCE: ARMY SAR'S)

JUNE 1981 SAR

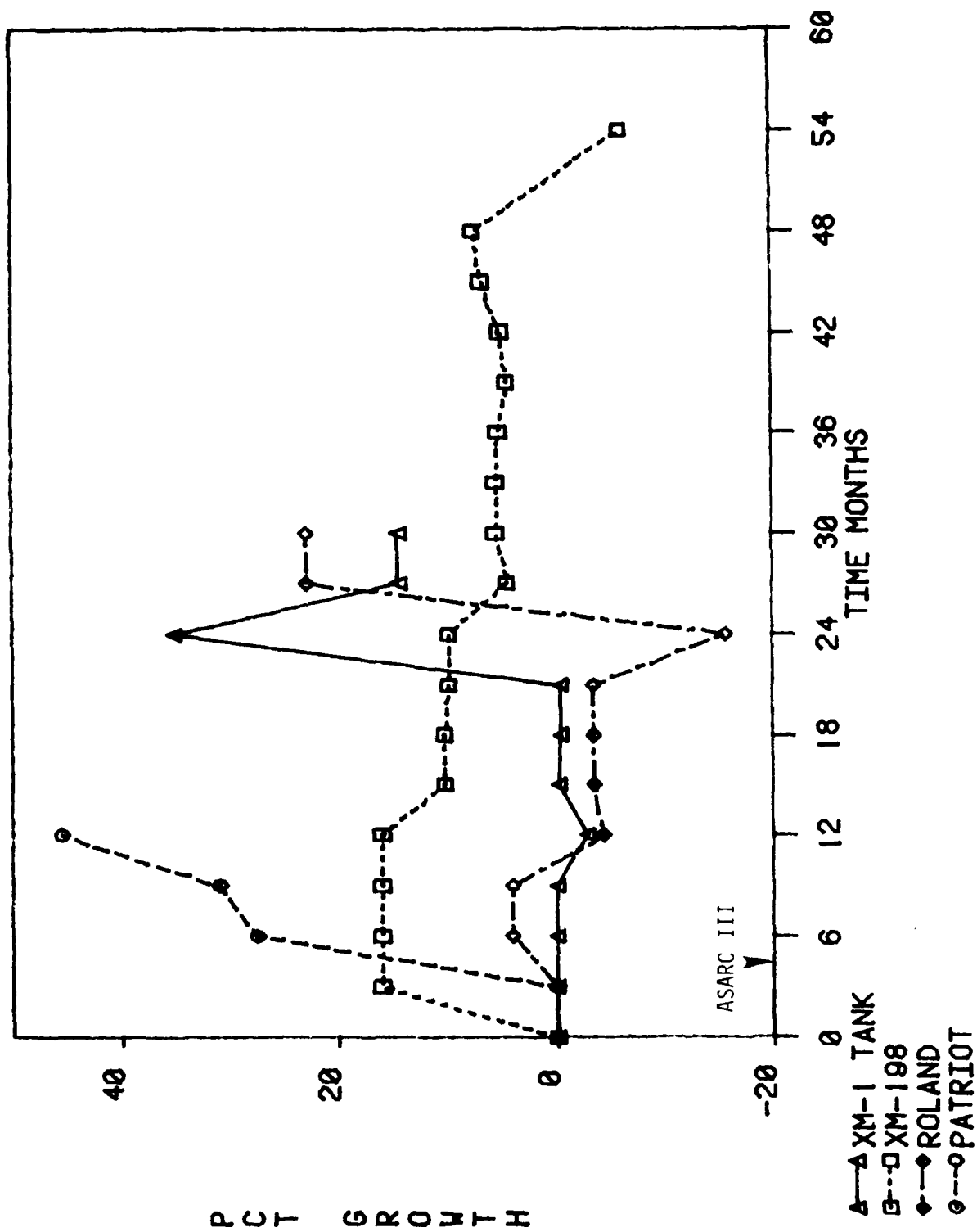


FIGURE 2.6 CUMULATIVE PROCUREMENT COST GROWTH (2)
(SOURCE: ARMY SAR'S)

JUNE 1981 SAR

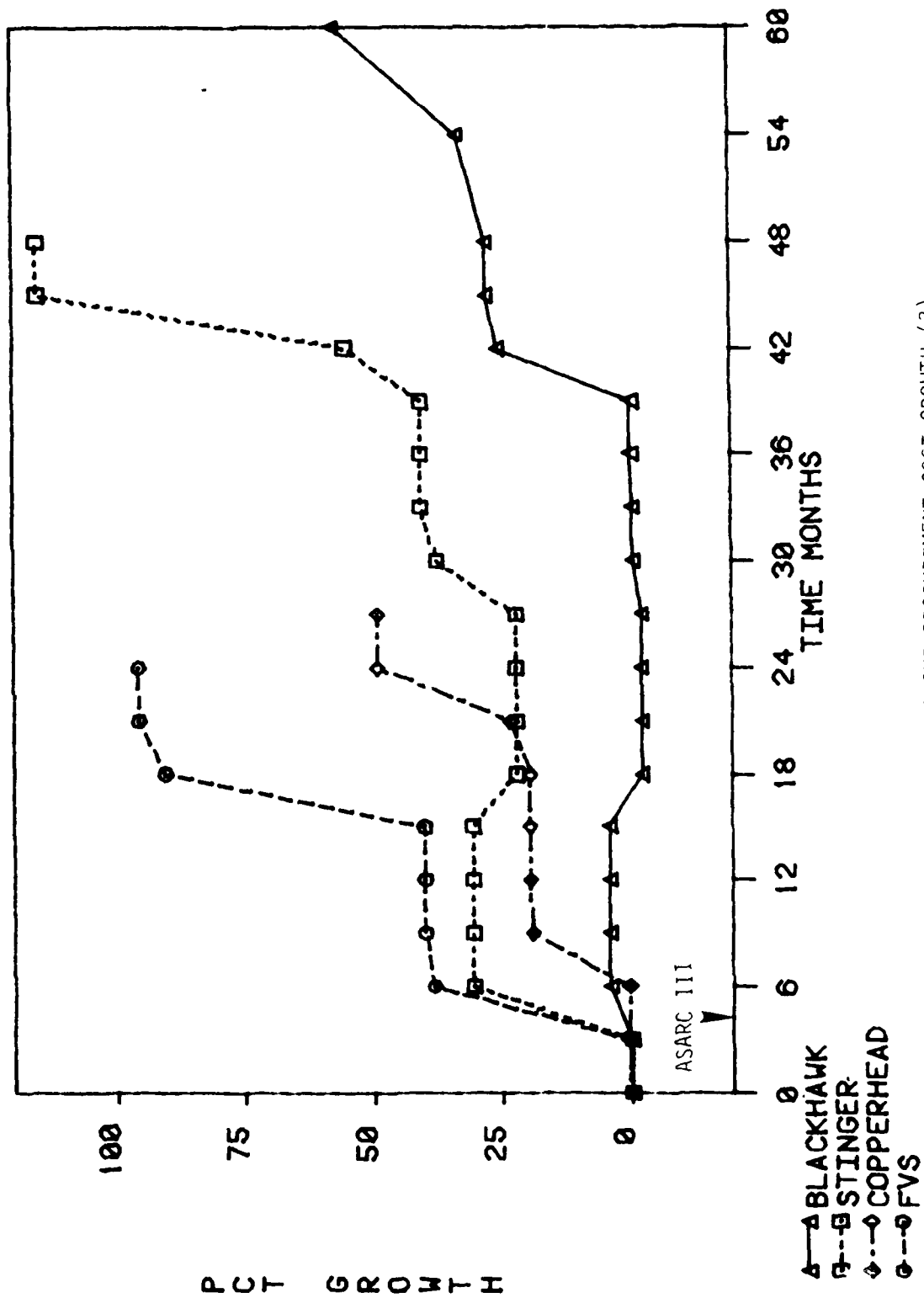


FIGURE 2.7 CUMULATIVE PROCUREMENT COST GROWTH (3)
(SOURCE: ARMY SAR'S)

- a. design instability
- b. new production facility
- c. inadequate PEP
- d. production rate changes
- e. management problems
- f. sole source contracting
- g. optimistic estimates
- h. new production processes
- i. software problems
- j. PIP's
- k. lack of skilled people
- l. workforce instability
- m. inflation
- n. testing problems
- o. long lead items
- p. production stretchouts
- q. requirements changes
- r. concurrency
- s. inadequate facilitization
- t. quantity changes
- u. politics
- v. shortage of specialized contractors
- w. budgetary constraints
- x. inaccurate learning curves
- y. workarounds
- z. exotic materials

But more likely than not, production stretchouts or quantity changes, for example, were merely precipitates of something else - inflation, perhaps. It is believed that understanding the relationships among the root causes of transition problems and cost growth is key to developing a useful methodology for assessing initial production risk.

Based upon this analysis and a recognition that past problems identify potential future risks, a risk structure was empirically developed to address initial production risk. There are numerous ways to categorize and relate production risk. This study's criteria were that the structure not only capture and isolate the fundamental risk areas, but also maintain as much independence as practical among the individual areas. This facilitates the statistical treatment of cost in the methodology developed in Chapter IV.

Figure 2.8 shows the empirically developed structure for initial production risk. There are three major groups: (a) External, (b) Resource, and (c) System. Individual risk categories exist within each group. The Resource and System groups are considered to be internal to the PMO. Resource risks relate to the production activity itself and resources needed to produce the system. System risks are product oriented and stem primarily from inherent technological and design risks carried over into production. External risks are those outside the control of a PMO primarily in the requirements area. Chapter IV presents a detailed discussion of each group and the individual risk categories.

Using the risk structure in Figure 2.8, the problems experienced by selected Army systems during the transition period are summarized as shown in Table 2.3. An "X" in a cell indicates that a problem was cited by a key individual(s) in the PMO or prime contractor. The problems cited are accommodated by the respective risk categories. Table 2.3 only indicates the relative frequency of problem occurrence based on the systems reviewed. But, the fact that the risk structure accommodates the reasons for cost growth as seen by key experienced individuals is important for the successful development of a production risk assessing methodology.

In an attempt to gain a more indepth understanding of the responses, problems cited were arrayed by risk category on an individual basis, Table 2.4. The number in each cell represents the number of key individuals within a PMO or prime contractor who cited a problem relating to the risk category as a reason for Procurement cost growth. However, it must be pointed out that since the opportunities for discussion with personnel within each system were not uniform, the strength of association between frequency of response and degree of impact could not be determined. The time allotted and method employed did not permit the quantification of impact intensity.

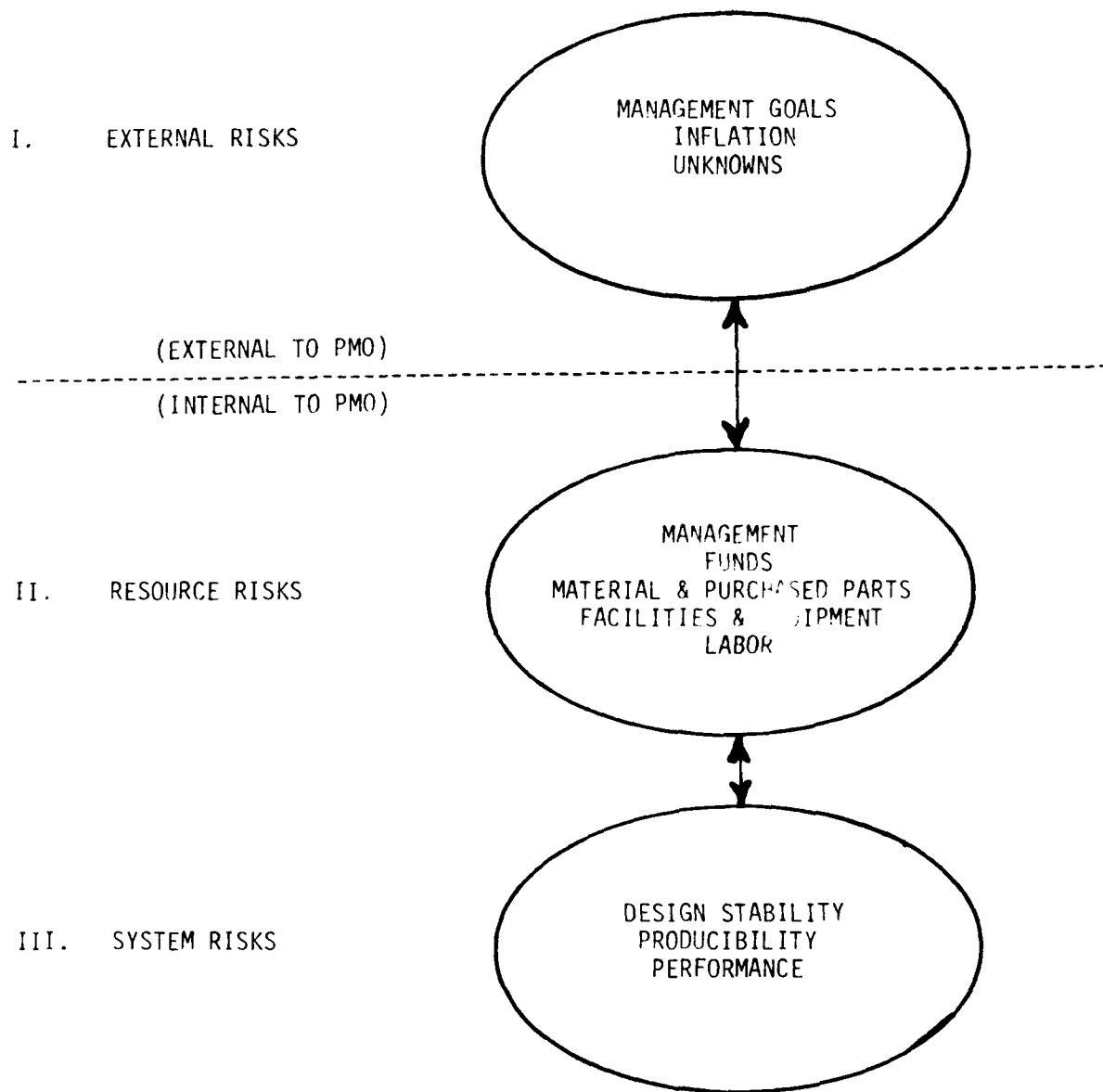


FIGURE 2.8 INITIAL PRODUCTION RISK CATEGORIES

TABLE 2.3 SUMMARY OF TRANSITION PROBLEMS
EXPERIENCED BY SELECTED ARMY SYSTEMS

SYSTEM												
RISK CATEGORY		A	B	C	D	E	F	G	H	I	J	TOTAL
I.	EXTERNAL											
	A. Management Goals	X	X	X	X		X	X	X	X	X	9
	B. Inflation	X		X	X		X	X	X	X	X	8
	C. Unknowns						X		X			2
II.	RESOURCE											
	A. Management	X		X		X	X	X	X	X	X	8
	B. Funds	X	X	X	X		X		X	X	X	8
	C. Material	X	X	X			X	X	X		X	7
	D. Facilities		X	X		X		X	X	X	X	7
	E. Labor	X				X		X	X	X	X	6
III.	SYSTEM											
	A. Design Stability	X		X	X	X	X	X	X	X	X	9
	B. Producibility		X			X			X	X	X	5
	C. Performance	X	X	X					X		X	5

TABLE 2.4 TABULATION OF TRANSITION PROBLEM
CITATIONS FOR SELECTED ARMY SYSTEMS

RISK CATEGORY	SYSTEM											CITATION FREQUENCY
		A	B	C	D	E	F	G	H	I	J	
I.	EXTERNAL											
	A. Management Goals	1	1	3	1	0	4	3	7	4	4	28
	B. Inflation	1	0	3	1	0	4	3	7	7	4	30
	C. Unknowns	0	0	0	0	0	4	0	7	0	0	11
II.	RESOURCE											
	A. Management	1	0	3	0	2	4	3	5	7	4	29
	B. Funds	1	1	3	1	0	4	0	7	7	4	28
	C. Material	1	1	3	0	0	4	3	5	0	4	21
	D. Facilities	0	1	3	0	2	0	3	5	7	4	25
	E. Labor	1	0	0	0	2	0	3	2	7	4	19
III.	SYSTEM											
	A. Design Stability	1	0	3	1	2	4	3	7	7	4	32
	B. Producibility	0	1	0	0	2	0	0	5	4	4	16
	C. Performance	1	1	3	0	0	0	0	5	0	4	14

CHAPTER III

RISK ASSESSMENT

A. INTRODUCTION.

It is commonly recognized that an R&D effort implies risk. The Army has developed a procedure using TRACE to incorporate risk analysis into the RDT&E budgeting process.

An analysis of pertinent literature and personal interviews indicate there is also significant risk associated with the transition from R&D into production. Therefore, TRACE and similar techniques were investigated for possible application to initial production risks.

B. TRACE FOR R&D.

1. Concept.

The TRACE concept was formulated to provide realistic cost estimates and thereby minimize subsequent disruptive reprogramming actions. It was designed to minimize cost overruns without resorting to gross overbudgeting. Specific emphasis is on allocation of funds to reduce the cost growth effects resulting from the occurrence of events that could not be programmed because of the lack of certainty that they would materialize.[37]

It is impossible to exactly predict the cost of a project. In reality, the final cost of a project will fall somewhere within a distribution as shown in Figure 3.1. TRACE is a point estimate selected from that distribution such that its probability of being exceeded is at an acceptable level. Figure 3.1 shows the TRACE as having an equal (50/50) probability of underrun and overrun, but another point such as 60/40 or 70/30 could have been selected. When the Baseline Cost Estimate (BCE) is placed on

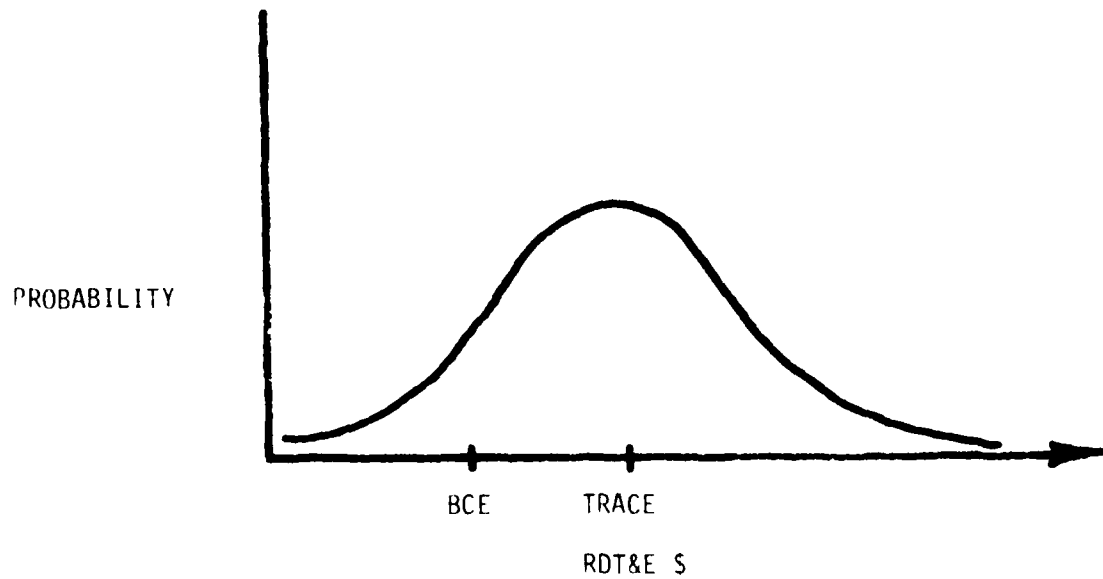


FIGURE 3.1 POTENTIAL RDT&E COST DISTRIBUTION

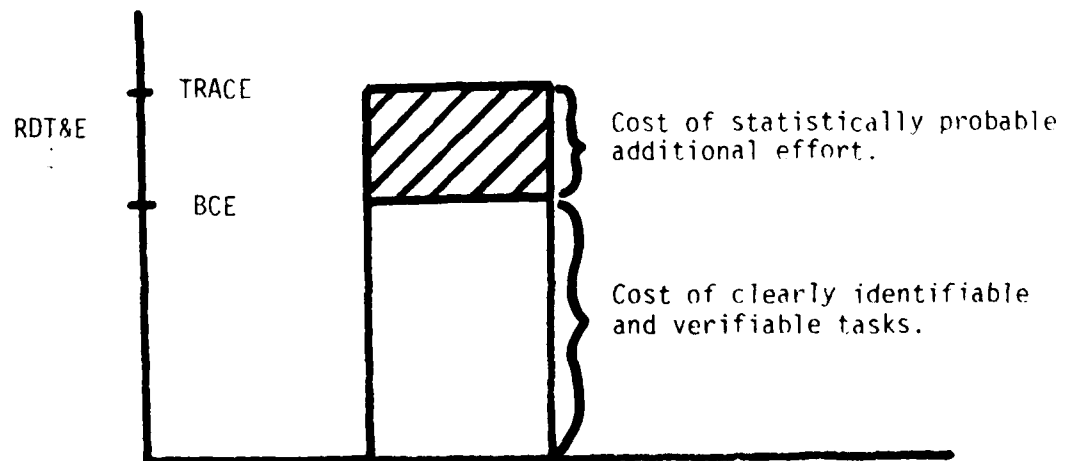


FIGURE 3.2 TRACE CONCEPT

this distribution of possible costs, it will fall to the left of the TRACE. The BCE is calculated from engineering estimates of specifically programmed activities, and although it generally includes some contingency, it does not include consideration for many uncertain activities that are statistically probable. This is further illustrated in Figure 3.2.[38]

2. Mechanics.

The PMO calculates a BCE and a TRACE and submits them through channels to Headquarters, Department of the Army (HQDA). The BCE represents project target cost. The TRACE is used for programming/budgeting and as the cost entry in the Five Year Defense Plan (FYDP). Upon budget approval by DOD/Congress, the BCE amount is released to the PM for program execution. The remainder known as "TRACE deferral," is retained by HQDA to serve as a source of funds for the PM to draw upon when justified to accomplish additional uncertain activities.

The retention of TRACE deferral funds by HQDA allows for managerial control and possible cost savings. These deferral funds are on a line item and fiscal year basis, and each year's funds are available for obligation for two years. During the fifth quarter of availability, the PMO must decide whether to release the funds to HQDA for reprogramming. The funds will be automatically reprogrammed if no action is taken by the seventh quarter. Any request by the PM to obtain deferral funds must be accompanied by sound justification within established guidelines. For example, funds will not be used to offset costs of major requirements changes which instead will be accommodated by restructuring the program and recomputing the TRACE.

3. Lessons Learned.

TRACE for RDT&E has been applied by the Army since the 6 March 1975 "Letter of Instruction (LOI) for Implementation of RDTE Cost Realism for Current and Future Development Programs." Between FY 76 and FY 84, TRACE has been applied to 31 programs. As of FY 81, TRACE has been credited with avoiding 17 reprogramming actions and avoiding 27 Congressional approvals.[12] The number of programs using TRACE and the amount of TRACE funding have increased as shown in Figure 3.3. Those programs that have more recently used TRACE have relied on TRACE as a greater percentage of RDTE funding in the TRACE funded years than earlier TRACE programs, as shown in Figure 3.4. Thus TRACE for R&D has become generally accepted and useful.

TRACE for R&D does have some problems however, that should be addressed as potential pitfalls for application to initial production.

a. Initially, PM's were hostile to the concept of project funds being held in reserve by DA.[40]

b. In theory, approximately one-half of the programs using TRACE should not need all of their programmed TRACE funds and the other half should need more than the amount programmed. In reality though, very few (5 times out of 88 potential) programs from FY 76 - FY 81 have turned in unused TRACE funds in a fiscal year. Two possible explanations are that TRACE may have been historically underestimated (or underfunded) or that TRACE becomes a "self-fulfilling prophecy."

c. TRACE methodology has been criticized as too subjective, too resource demanding, too restrictive, and too inflexible.[18]

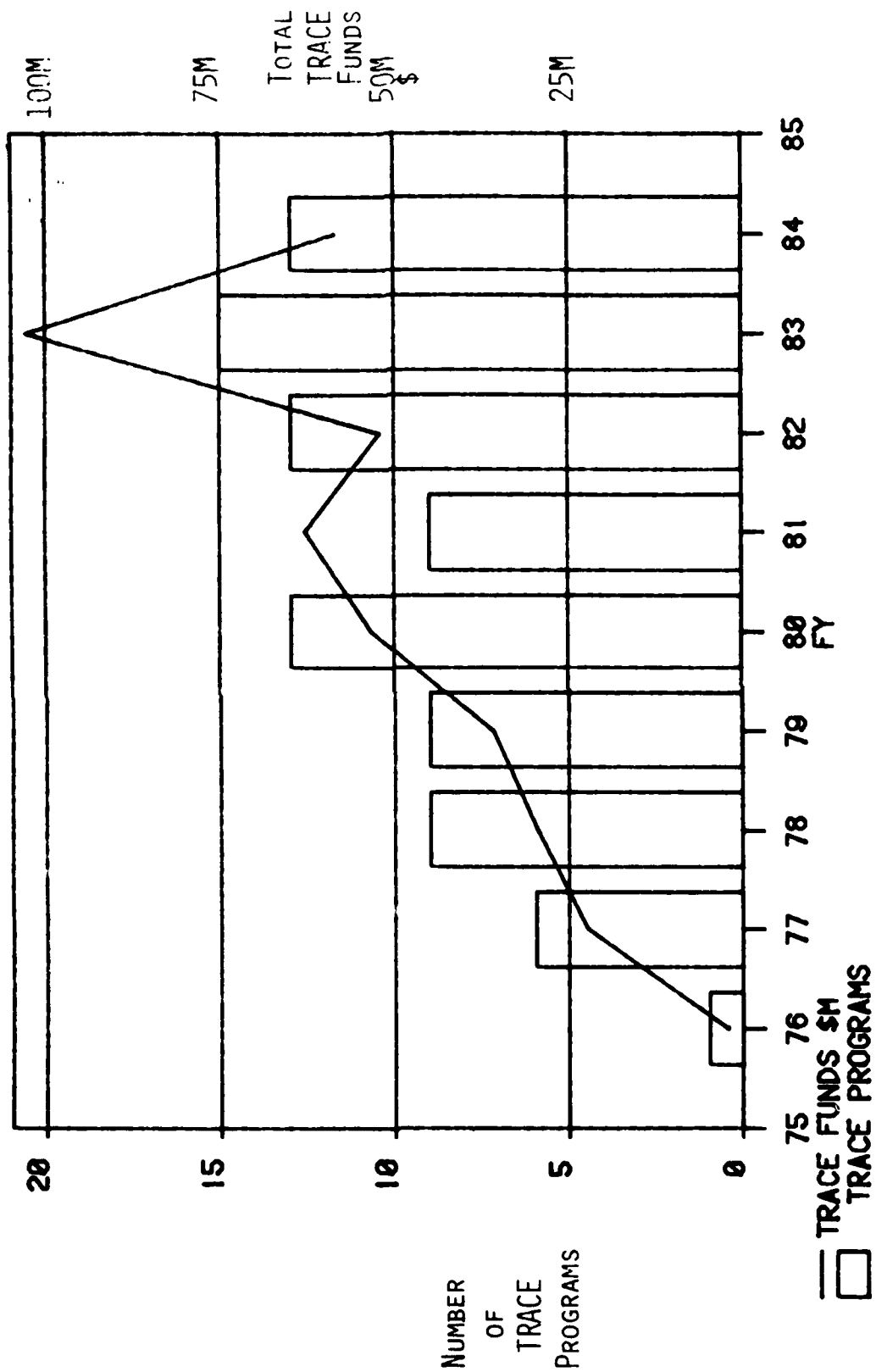


FIGURE 3.3 ARMY TRACE APPLICATIONS
(SOURCE: ODCSRDA)

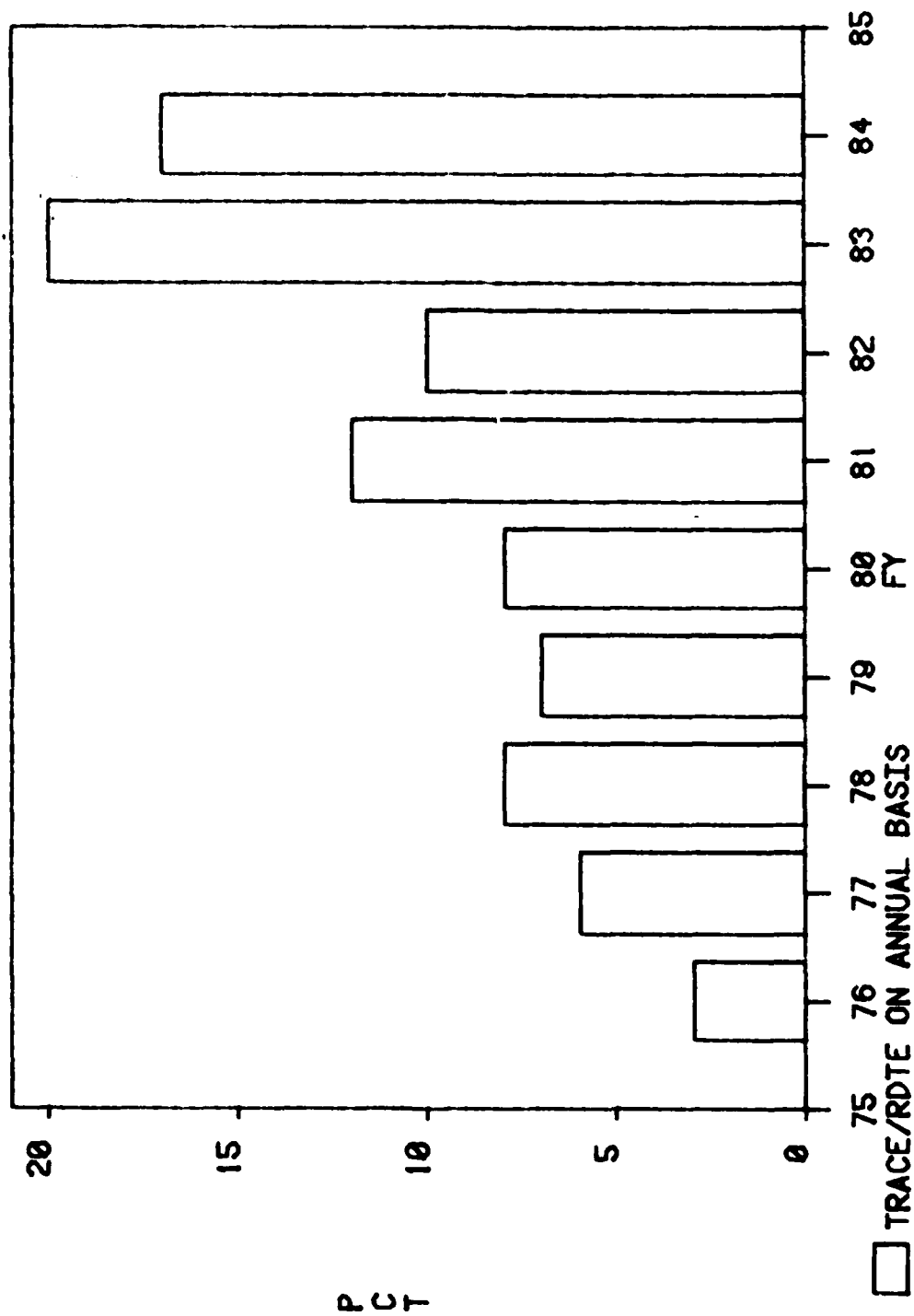


FIGURE 3.4 TRACE AS A PERCENTAGE OF RDT&E FOR
SELECTED ARMY SYSTEMS (SOURCE: ODCSRDA)

d. TRACE has not eliminated RDTE overruns.[32, 34]

4. Methodology.

A survey of 20 Army PMO's that had TRACE experience found that three principal methodologies were used to compute TRACE, with some unique variations.[18] The three methods were classified as Risk Percentage, Risk Factor, and Probabilistic Network Models. A fourth method, called Probabilistic Event Analysis or Risk Tabulation was not found to be used by any PM. These four methodologies are as follows:[39]

a. Risk Percentage.

The Risk Percentage method is an undocumented procedure in which the TRACE is computed by adding a percentage (10 - 15%) to the BCE at a summary level. The percentage is subjectively determined by experts based on past experience, risk assessment and judgment. Time phasing is accomplished subjectively or assuming proportionality to the RDTE effort. This method, although used, has not been formally approved because of similarities to contingency fund or management reserve concepts.

b. Risk Factor.

The Risk Factor approach described in the 1975 LOI computes TRACE by assigning risk factors to discrete Work Breakdown Structure (WBS) elements of the BCE. After estimating WBS element costs as part of the RDTE BCE, each element is assessed for uncertainty by experts. Historical data on previous similar systems is used when available, but most risk factors are subjectively determined. A factor represents the cost increase expected for a WBS element as a result of technical uncertainty associated with that particular element plus the interrelated uncertainties associated with other WBS elements that interface with it. By multiplying each

WBS cost by its risk factor, a TRACE is computed. Time phasing is subjective or assumed proportional to BCE time phasing.

Advantages of this approach are: (1) analysis does not require a high analytical skill level; (2) analysis can be performed quickly and inexpensively in comparison to computer modeling; (3) analysis can be easily understood; and (4) quality of analysis can be easily evaluated by management.

The most serious disadvantage of this approach is in the determination of the risk factors. Because of the apparent simplicity of the approach, there might be a tendency to use the risk factor as simply a "fudge factor." To handle the factor in such a manner would reduce the credibility of the cost estimate. In addition, the factor is implicitly assumed to be constant for each element throughout duration of the project.

c. Probabilistic Network Modeling.

Probabilistic Network Modeling is a combined approach using Program Evaluation and Review Technique (PERT) principles and Monte Carlo simulation techniques. Various computerized models can be used for this application, including VERT, RISCA, and RISNET.[39] An R&D program is first displayed as a network of interrelated events and activities. Cost, schedule and technical uncertainties associated with the various activities are then estimated. The model iteratively simulates the activities and events to produce time - phased cost and schedule distributions for the program. The analyst can adjust the TRACE to levels reflecting desired probability of cost overrun vs. cost underrun. This method is the most rigorous and resource demanding, but it is the most precise and risk inclusive.

Advantages of this approach are: (1) explicit consideration is given to activity interaction; (2) the TRACE may be selected from the total cost distribution as output; (3) the form and collection of output is flexible; (4) the model can be easily modified and rerun to answer "what-if?" questions; (5) the network can estimate the BCE by fixing schedules and removing uncertain/contingency/fallback activities; (6) the network can serve as a management tool to track and control, as well as predict time and schedule; and (7) the network can be used to satisfy the Decision Risk Analysis requirement.

Disadvantages of this approach include: (1) a high skill level is required to build the network and collect data; (2) the output can be sensitive to the network logic; (3) it is difficult to reconcile this approach with the WBS; (4) the cost is initially high; and (5) it requires considerable data collection.

d. Probabilistic Event Analysis.

Probabilistic Event Analysis, or Risk Tabulation, was developed by John M. Cockerham and Associates, Inc. to correct perceived deficiencies in the Risk Factor approach. Risk for each WBS element is separated into two categories in an effort to assess interactive effects between WBS elements. Internal (stand alone or isolated) risks are assessed as well as the external (interactive) risks. Using conditional probability theory, the overall program cost risk is tabulated. Uncertainties assessed as probability values are determined essentially in the same manner as risk factors. Time phasing can be incorporated into the calculation by estimating when the various risks will occur for each WBS.

Advantages of this approach are that it is relatively easy to use, and it addresses interaction between elements so it should give better results than the Risk Factor approach. Disadvantages are (1) it is highly dependent upon the skill of the analyst to identify and account for the various interdependencies; (2) it is sensitive to errors in subestimates and; (3) the TRACE uses the BCE as a basis and is subject to the same bias as the BCE.

C. INVESTMENT PHASE MANAGEMENT RESERVE (IPMR).

In addition to the TRACE techniques applied to the R&D phase, a separate approach has been developed and applied on two Army systems to establish a management reserve for the Investment Phase.[36] Uncertainty elements were defined separate from the BCE structure, but are related to the BCE through an adjustment to the Design-to-Unit-Production-Cost (DTUPC). These uncertainty elements are: Production, Performance, Sizing, Technology, Resources, Management/Control, Higher Management, and Other. Triangular cost distributions are estimated for each uncertainty element through subjective assessments of major subsystem risk which are then related to the DTUPC. The cost distributions are combined using Venture Evaluation and Review Technique (VERT) which generates a single cost distribution with a mean usually exceeding the DTUPC. The difference between the DTUPC and the mean (or some other value from the single cost distribution) is the basis for the management reserve.

Advantages of the IPMR approach are: (1) the uncertainty elements were specifically designed for production; (2) the analytical techniques used are relatively simple to explain; (3) it is flexible in that

different confidence levels for risk can be used; and (4) the triangular distribution parameters are easily estimated. Disadvantages are (1) there is interdependency among the uncertainty elements; (2) it requires accurate DTUPC estimates; and (3) it was intuitively developed for a specific system.

CHAPTER IV
PRODUCTION RISK ASSESSING METHODOLOGY

A. INTRODUCTION.

From the discussion of risk and TRACE for R&D in Chapter III, it appears there are a number of possible ways to assess initial production risk. The approaches for R&D TRACE could similarly be applied to the production WBS and BCE. The Risk Factor approach, for example, which is popular for R&D TRACE, could simply be used to adjust the BCE cost elements to include a TRACE amount for production. But the BCE's already include some consideration of risk using a judgment approach similar to the Risk Factor, and yet, underfunding continues to plague programs. Recent history of inaccurate estimates using the BCE, as evidenced by the Army SAR's, shows something more is needed - something that specifically addresses production risk and the synergism of the various production cost elements.

One approach that attempts to do this is the Investment Phase Management Reserve methodology.[36] This methodology proceeds in the right direction but can also be improved upon.

B. TAXONOMY OF INITIAL PRODUCTION RISKS.

A different perspective of initial production risk was taken to improve upon the shortcomings of the current techniques. A recognition that past production problems represent risk areas for future systems suggested an empirically developed risk structure which specifically addresses initial production uncertainty. To develop this structure, an extensive list of initial production problems recently experienced by

selected Army PMO's was compiled from field interviews. This list was supplemented by a data search and discussions with experienced government and contractor personnel outside the PMO's. By deductively applying classical production management theory to these "real world" problems, the major risk categories evolved as illustrated in Figure 2.8.

This figure illustrates that a weapon system, constrained by limited resources, must be produced within a dynamic environment of external forces. The major groups of "System Risk" and "Resource Risk" are within the purview of the project manager/contractor, while the group labeled "External Risk" is beyond their control. The arrows in Figure 2.8 depict the relationship between these three categories as a continuous two-way flow of information.

Figure 4.1 further illustrates these relationships as a taxonomy in which the inner circle represents System risks, the middle ring represents the resource constraints, and the outer ring represents the external risks. Within this context, the three major groups (System, Resource, External) were further subdivided into a comprehensible risk categories as described below.

1. System Risk.

The ideal situation is when the design has been virtually stabilized prior to initial production, all aspects of producibility have been incorporated into the technical data package and production line items subsequently meet all performance specifications. In reality, this never occurs due to inherent uncertainties in design stability, producibility, and performance, as described below.

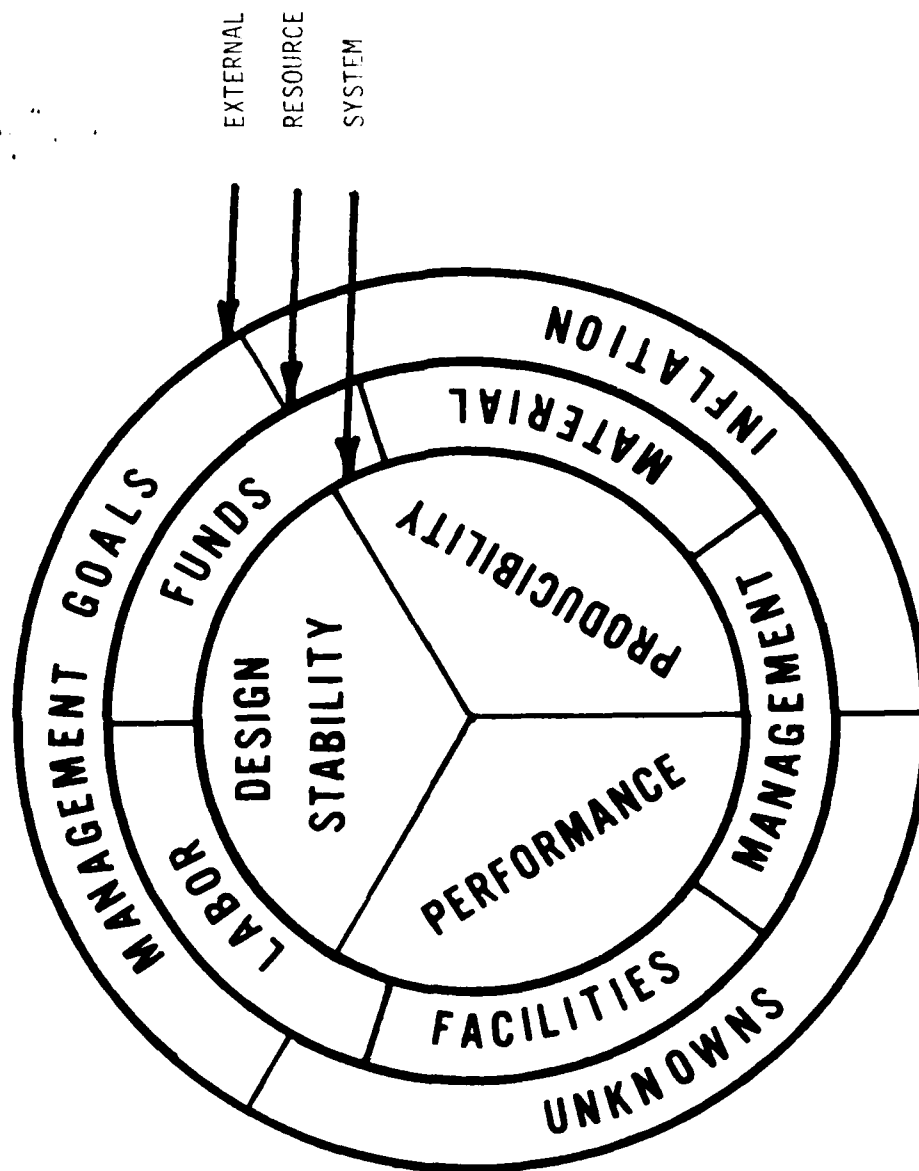


FIGURE 4.1 TAXONOMY OF INITIAL PRODUCTION RISK

a. Design stability.

This refers to the level of design stability when entering initial production. If design problems have not been resolved during R&D, the attendant uncertainties will carry over and disrupt initial production. Indicators of risk level in this category include but are not limited to:

- (1) program concurrency
- (2) configuration changes
- (3) testing requirements and results.

b. Producibility.

It is essential that sufficient attention be directed to producibility aspects during R&D; otherwise, the result will be severe disruptions and increased cost during initial production. Indicators of risk level in this category include:

- (1) adequacy of PEP program
- (2) adequacy of MM&T program
- (3) sophistication of manufacturing processes
- (4) custom made prototypes.

c. Performance.

Problems can occur with system performance even if design has stabilized and the item is producible. This risk area includes all the "ilities" (reliability, availability, maintainability, dependability, capability, etc.) required to meet rigid performance specifications. If increasingly sophisticated performance requirements continue to drive weapon designs, performance will remain an area of high uncertainty. Indicators of risk level in this category include:

- (1) state-of-the-art technology
- (2) exotic testing requirements
- (3) extent of PIP activity.

2. Resource Risk.

The system requirements of design, producibility, and performance are merely academic unless resources are available to accomplish them. These resources can be succinctly divided into the five fundamental categories of material, facilities, labor, funds, and management. The increasing demands on these finite resources ensure this as a continuing risk group.

a. Material.

This resource refers to all materials and purchased parts going into the weapon system and its direct support equipment. It includes raw material in addition to specialized vendor items such as electronic components, engines, transmissions, etc. Problems may occur at the prime contractor, subcontractor or vendor levels. Indicators of risk level in this category include:

- (1) exotic/strategic materials
- (2) long lead times
- (3) turbulence in specialized vendor industries.
- (4) sole source/proprietary vendors

b. Facilities.

This resource includes brick and mortar needs as well as manufacturing and testing equipment and tooling. Facilitization risk varies depending on whether existing facilities are modified or new facilities are designed and built. The increasing sophistication of weapon systems brings new and exotic equipment and tooling requirements.

Indicators of risk level include:

- (1) state-of-the-art manufacturing equipment
- (2) manufacturing equipment lead time
- (3) new versus existing manufacturing facilities.

c. Labor.

Labor remains a major contributor to weapon s, cost.

Competition for scarce skills in such critical fields as engineering, software design, welding, machining, heavy equipment use and maintenance make this a high risk category. Indicators of risk level include:

- (1) labor availability
- (2) demand for scarce skills
- (3) training requirements
- (4) personnel turnover.

d. Funds.

Keen competition for limited funds at all levels of government and industry from departmental/corporate level to project level causes uncertainty. The complicated process by which funds are estimated, requested, appropriated and obligated adds to the uncertainty. Inadequate funding, if even for a short period of time, can result in severe program perturbations that ultimately result in cost growth. Indicators of risk level in the funding category include:

- (1) optimism in cost estimating
- (2) timeliness of funds
- (3) contractor cash flow.

e. Management.

This risk category includes the sufficiency and experience

of management personnel in both the contractor and project management offices and general manageability of the project. In this context management is just as much a resource as material, facilities, production labor, and funds. Management decisions, particularly in the planning and controlling functions, have tremendous potential cost impact.

Indicators of risk level include:

- (1) management turbulence
- (2) relationship between PMO and contractor(s)
- (3) production management experience
- (4) available management information systems
- (5) management complexity.

3. External Risk.

This group represents uncertainties over which program management and contractor personnel have no control. These uncertainties constitute the dynamic environment in which finite resources are allocated to the production of many systems. The three major categories, as described below, are management goals, inflation, and unknowns.

a. Management goals.

There are numerous layers of management above the program manager that are continually interpreting threats and establishing goals. These include cost, schedule, quantity and performance goals. The resulting guidance to the PMO often changes, redirecting the program and causing perturbations that ultimately cause cost growth. Indicators of risk level include:

- (1) political environment
- (2) project priority
- (3) program/requirement changes.

d. Inflation

There is uncertainty in estimating future inflation rates. Inaccurate projections of inflation can result in substantial program underfunding which contributes to apparent cost growth in two ways. First, the underfunding compared to actuals is generally interpreted as a cost overrun. Second, the lack of funds causes program disruptions which result in redirection of resources and cost growth.

c. Unknowns.

This risk category includes such occurrences as natural disasters, civil disorders, labor strikes, fires, and major program setbacks such as prototype crashes or sabotage. These risks cannot be accurately anticipated but history shows that they do occur.

C. PRODUCTION RISK ASSESSING METHODOLOGY (PRAM).

The risk structure described above was empirically developed from extensive personal interviews and a literature survey of the causes of "transition" problems. It was derived independently of standard cost categories (i.e., the BCE, SAR, etc.) and is not influenced by their innate biases. The structure is understandable in that it conforms to traditional production categories. It is flexible because risk costs can be calculated at any level (i.e., system vs. subsystem); it is not system unique; and all eleven categories need not be used. The eleven basic categories are reasonably independent if care is taken not to credit a particular risk to more than one category. The structure is inclusive in the sense that all potential "transition" problems gleaned from the interviews/literature search fit into the eleven categories.

Accepting the above risk structure, an attempt must be made to quantify each risk category as it applies to a specific system and/or subsystem and relate it to production cost. Obviously, answering the question "how much?" for each risk area is not always easy. Some categories such as Inflation or Facilities are relatively easy to quantify using the BCE data as a base. Others, such as Producibility or Management, are much more difficult and must rely primarily upon sound judgment. The appropriate cost estimating approach for a risk category should be used, whether it is the Industrial Engineering approach, parametric, analogy, educated guess or some combination. There is no "best way" to quantify all risk categories.

This union of conventional cost estimating techniques with the initial production risk structure constitutes a methodology to assess and quantify production risk. Titled Production Risk Assessing Methodology (PRAM), it should not be confused with a direct application of a TRACE technique to production risk.

The objective of the PRAM is to develop individual cost distributions for those high risk categories pertinent to the weapon system being analyzed. The inclusion of any risk category in a PRAM exercise is optional since unusual production risk may not be present in all categories for a given system or subsystem.

If subsystem risks are to be analyzed separately and then combined into a system level individual cost distribution, care should be taken

to separate the risk impact as appropriate among the subsystems. For example, if labor is a high risk area for both the frame and propulsion subsystems, care should be taken not to include frame labor risk in the propulsion labor risk assessment and vice versa. "Double counting" in the risk assessments, whether system or subsystem level, will serve to inflate the final risk cost figures.

Frequently, the individual cost distributions can be described with three values (low, medium, and high) and assumed to follow a triangular probability distribution. However, any probability distribution can be used, as long as it is appropriately descriptive of the actual risk. Figure 4.2 shows the summary format that should be completed from risk cost calculations for a PRAM exercise.

The cost elements in the BCE should be used where appropriate to assist in developing the risk-cost distributions, although it is not necessary in all cases.[7] For example, Non-Recurring Investment (2.01) and Sustaining Tooling (2.023) relate to the facilities and equipment risk category; Recurring Engineering (2.022), Quality Control (2.024) and a portion of Manufacturing (2.021) relate to the labor risk category; another portion of Manufacturing (2.021) relates to the materials risk category; and Engineering Changes (2.03) and System Test and Evaluation (2.04) relate to the design stability risk category. The BCE values should be noted when present in a cost distribution.

Once the cost distributions are determined and parameters calculated for the appropriate categories, the individual risk costs can be calculated for each category by subtracting the BCE value, where present, from the mean PRAM estimate. Summing the individual risk costs yields the system Total Expected Risk Cost.

TOTAL EXPECTED RISK COST SUMMARY

SYSTEM/SUBSYSTEM:		BCE	PRAM COST ESTIMATES				VAR	EXPECTED RISK COST
RISK CATEGORY			LOW	MEDIUM	HIGH	MEAN		
EXTERNAL	MGMT GOALS							
	INFLATION							
	UNKNOWN							
RESOURCE	MANAGEMENT							
	FUNDS							
	FAC/EQUIP							
	MAT/P. PARTS							
SYSTEM	LABOR							
	DESIGN STABILITY							
	PRODUCIBILITY							
	PERFORMANCE							
TOTAL EXPECTED RISK COST =								

FIGURE 4.2 FORMAT FOR TOTAL EXPECTED RISK COST SUMMARY

The Total Expected Risk Cost is the mean or expected value of the convolved risk cost distribution. If a particular level of confidence is desired, the variance of the risk cost distribution must also be determined and used to adjust the total risk cost. Due to independence, the variance can be calculated by summing the variances of the individual cost distributions. It can also be determined by combining the estimated PRAM distributions using techniques such as VERT.

Once the total risk cost is determined, the Production Risk Assessing Cost Estimate (PRACE) can be calculated. PRACE is defined as the sum of the BCE Investment Cost and the total risk cost just as TRACE is the sum of the BCE for RDT&E and the R&D risk cost. It should be noted that the BCE values shown on the Total Expected Risk Cost summary account for only the appropriate portion of the total BCE Investment Cost. Also, based on the cost growth experience shown in Figure 2.4, the total risk cost should be budgeted over the first three years of production to coincide with the production rate buildup and the period of probable disruption. PRACE funds should be available when needed to minimize the impact of disruptions. Figure 4.4 on page 55 illustrates the relationships among the BCE, Total Expected Risk Cost, and PRACE for an example PRAM exercise.

A sensitivity analysis may be conducted on soft data to determine impacts of any estimating errors. Automating the PRAM algorithm facilitates sensitivity analyses.

A PRACE should be developed at least three times before Milestone III. The first PRACE should be prepared roughly two years prior to Milestone III to insure funds can be programmed for the early production years. A PRACE can be developed earlier than this, say at ASARC II, but there is still

considerable uncertainty in the program then that will be reduced later in FSED. The second PRACE should be prepared about a year after the first to meet the budget requirements for the early production years. The third PRACE should be prepared to support the ASARC III decision. Each update will be more accurate than the previous PRACE as additional information is available and there is less uncertainty in the design.

D. PRAM EXERCISE.

The following example illustrates the proposed PRAM and establishment of cost distributions for the various risk categories. In this example, a new generation weapon system, called "System-X," is about two years prior to ASARC III. A BCE has recently been completed and validated. A PRACE for the first three years of production is to be derived by investigating each risk category.

1. Management Goals.

This weapon system is viewed by Congress and the Defense establishment as essential to our defense over the next decade. Its high priority and high price tag have resulted in considerable public scrutiny. No major program redirections have been dictated by it thus far. However, due to increased tension in the Middle East, it is anticipated that the IOC will be moved up and quantity requirements will be increased. Any such program change would have a cost impact during the transition production period and may require a reprogramming action with recomputation of BCE and PRACE. Therefore, no PRACE cost funds are included at this time.

2. Inflation.

The BCE is based upon a DOD directed inflation rate of 6.5 per

annum. However, this is only an estimate. Economists predict that actual inflation during this period could run as low as 4.0% or as high as 15.0%. This uncertainty is readily translated into a dollar range around the BCE. If the BCE escalation amount (i.e., difference between constant and current dollar estimate for first three years of production) of \$200.M is treated as the most likely value, the lower limit is \$140.M and the higher limit is \$660.M.

3. Unknowns.

The facility planned for low rate initial production is located along an earthquake fault. Minor tremors occur infrequently so this is viewed as low risk. However, if any damage does occur due to a tremor, the program disruptions may eventually impact the initial production period. Another risk is that labor negotiations at the prime contractor are due approximately 6 months prior to the start of production. A strike is viewed as having a low probability of occurrence and a cost impact cannot be probabilistically attributed at this point.

4. Management.

System-X will experience unusually high management risk during initial production due primarily to three causes. First, the PMO does not have the desired level of production experience on its staff and is experiencing difficulties in hiring this expertise due to non-competitive salaries with private industry. Second, the prime contractor plans to be essentially a system assembler, relying upon an unusually large number of major subcontractors and GFE. Third, the relationship between the PMO and prime contractor is becoming increasingly adversarial. The cost impact of potential problems in this area of management were not incorporated

in the BCE. Through subjective assessments based upon analogous systems and discussions with MSC/PMO personnel, this cost impact was estimated as equally likely between 5% and 20% of the BCE amount. This results in dollar values of \$45.M to \$180.M, uniformly distributed.

5. Funds.

The prime contractor's cash flow position is currently tight, with funds available at historically high interest rates. However, the BCE is considered to be based on reasonable estimates and should cover planned activities. So, if a realistic PRACE is approved to cover uncertain activities, funds should not be a significant risk category.

6. Facilities.

This is considered to be a high risk category. The prime contractor plans to build a new production facility for high rate production in the "Sun Belt," far from the current R&D facility which is on the West Coast. Costs to build and equip the facility were "guesstimated" in the BCE, but there are a number of uncertain activities not addressed in the BCE. At this early date, the design and production aspects have not stabilized enough to determine actual facility/equipment requirements. By the time the production specifications have stabilized, there may not be enough lead time left to acquire the more sophisticated manufacturing equipment that is anticipated. Based on expert assessment of anticipated production requirements and equipment lead times, the cost impact over and above BCE estimates can be as high as \$20.M. The PM's and the prime contractor's position is that the BCE has a high probability of achievement with

progressively smaller chance of incurring additional costs up to the projected maximum.

7. Material.

At the present stage in SYSTEM-X's life, the main contributors to risk in this category are subcontracted software and strategic materials. To meet performance requirements, the system includes numerous computers and integrating software and three separate strategic materials. Software has been receiving considerable attention, and the "buns" are anticipated to be solved by ASARC III. The amount included in the BCE for strategic materials is considered to be the most likely value. However, the availability and price uncertainty of the strategic materials could result in additional cost impact during production. On the pessimistic side, investment speculation in such "hard" assets could conceivably drive the price up five-fold which translates to \$30.M. On the optimistic side, this same commodity market could bring the price down to one half of the price estimated in the BCE.

8. Labor.

This is considered to be a high risk category since the system will be produced in an area with little available manufacturing labor and most of the needed labor must be relocated. Using BCE data, it is determined that \$300.M has been estimated for labor cost which includes a 10% contingency factor. Labor shortages will cause disruptions resulting in increased labor expenses of overtime, rework, and training, for example. An additional \$180.M is determined to be adequate to cover the increased cost due to a labor shortage. This was calculated by assuming a 95% learning curve versus the 88% used for the BCE. This results in a labor

cost distribution with a \$270.M low, \$300.M from the BCE, and a \$480.M high value.

9. Design Stability.

There is substantial concurrency built intentionally into this program. The rationale is to correct minor design deficiencies during initial production and hopefully shorten the overall program. The intent of this management approach is to reduce the long term effects of inflation and reduce the total program cost. The risk involved with this approach is that design instability brings uncertainty to initial production. Therefore, additional funds must be readily available for numerous short term program disruptions stemming from retests, modifications, ECP's, workarounds, stretchouts, etc. If these funds are not available on a timely basis, the disruptions and consequential cost impacts will be compounded. A Delphi elicitation provided an estimated cost impact of \$8.M low, \$15.M medium, and \$40.M high. The BCE for related activities is \$10.M.

10. Producibility.

The R&D program has a small amount of money allocated to PEP. Up to this point, no funds have been expended on PEP effort. Based on experience with analogous but less sophisticated systems, the System-X PEP effort should be more substantial. Assuming that all the PEP funds will be spent on PEP rather than being diverted to solve R&D crises, there will still be risk during initial production. If a major producibility problem occurs during initial production, the cost impact is estimated to be \$12.M.

11. Performance.

Already, several changes have been made to stringent performance requirements. Strides in technology coupled with a changing threat posture have resulted in several PIP's and more are anticipated. The estimated cost impact, including probabilistic tasks not in the BCE is equally likely to occur within a range of \$15.M to \$35.M.

Summing the individual risk cost amounts for this example yields a Total Expected Risk Cost of \$352.5.M. Figure 4.3 shows a completed summary for the example.

The total risk cost must also be allocated over the first three years of production. Considering such things as the desired production rate buildup and the period of probable disruption, \$145.M is planned for the first year, \$140.M the second, and \$67.5M the third year. Figure 4.4 illustrates the breakout and relationships among the BCE, expected risk cost, and PRACE for this example.

E. SUMMARY.

PRAM represents more than just a breakout of risk cost; it provides a structure to describe the interrelationships between the various risk categories. It is relatively simple to apply and to explain, yet is mathematically rigorous in that it conforms to established and accepted statistical techniques. In other words, it is useable.

PRAM's shortcomings are those inherent in any operations research technique that requires subjective assessments for input. Although expert judgment has its limitations, it should not be discounted as being inappropriate but should be exploited.[33] It frequently is the best approach available.

TOTAL EXPECTED RISK COST SUMMARY

SYSTEM/SUBSYSTEM: SYSTEM-X		PRAM COST ESTIMATES					EXPECTED RISK COST
RISK CATEGORY	BCE	LOW	MEDIUM	HIGH	MEAN	VAR	
EXTERNAL							
MGMT GOALS							
INFLATION	200	110	200	560	333.3	13498.9	133.2
UNKNOWN							
RESOURCE							
MANAGEMENT FUNDS		45		180	112.5	1512.9	112.5
FAC/EQUIP	50	50	50	70	56.7	22.2	6.7
MAT/P. PARTS	6	3	6	30	13.0	36.5	7.0
LABOR	300	270	300	480	350.0	1350.0	50.0
SYSTEM							
DESIGN STABILITY	10	1	15	40	25.0	41.7	11.0
PRODUCIBILITY		12	12	12	12.0		12.0
PERFORMANCE	5	15		35	25.0	33.3	21.0
TOTAL EXPECTED RISK COST							= 350.5

FIGURE 1.3 SUMMARY OF PRAM EXPECTED

PRACE BREAKOUT

	YEAR 1	YEAR 2	YEAR 3	TOTAL
INVESTMENT PHASE BCE	350.	250.	300.	900.0
EXPECTED RISK COST	145.0	140.0	67.5	352.5
PRACE	495.0	390.0	367.5	1252.5

FIGURE 4.4 EXAMPLE PRACE BREAKOUT

CHAPTER V

CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION

A. CONCLUSIONS.

The Army continues to encounter problems in the transition of a weapon system from R&D to production which results in substantial cost growth. By analyzing 11 Army SAR systems during this transition, it was determined that a 35.5% average cost growth was occurring (excluding inflation and quantity changes) in the Procurement appropriation which amounts to over \$5 billion. Most production cost growth is evidenced during the first two years following Milestone III.

As in R&D, uncertainties are inherent to some degree in all new systems entering production. Risks cannot be totally eliminated in the transition of an Army major weapon system from R&D to production, but they can be reduced through such means as good Producibility Engineering and Planning (PEP), periodic Production Readiness Reviews (PRR), and experienced production management. Even with this effort, a PMO is still frequently faced with technological uncertainties carried over from R&D, and he usually is pushing the state-of-the-art in manufacturing processes and techniques. The trend toward more concurrency will increase these risks even more.

The funding environment further aggravates a PMO's problem and increases program risks. The production cost estimates must be made early during system development when there is still much uncertainty present. Also, competition among and within the Services for program acceptance forces optimistic estimates. These optimistic and uncertain estimates are then

established as targets and incorporated into the budget. When the actual costs are known, cost growth becomes apparent and there are not enough funds available to meet requirements. The program then experiences stretchout--which disrupts the planned production system--which again can increase costs.

Risk analysis techniques were analyzed for possible use in assessing production risk. Methodologies used in the Army's TRACE program were specifically reviewed as they are generally accepted and considered successful in addressing the R&D area. TRACE has reduced significantly the number of funding adjustments required for Army systems in FSED. Subsequently, there were fewer program disruptions due to funding delays.

It should be pointed out that almost all of the TRACE deferral funds available to PMO's have been utilized by that PMO. This is contrary to the original premise on which TRACE was developed; that is, roughly half of the systems will experience an overrun and half an underrun. It is probable that this will continue since PMO's will always have unfinanced requirements to justify receiving "their" TRACE funds even though the funds were not originally determined on this basis. It is important to realize that TRACE relies heavily on expert judgment to estimate the program risks; however, by its very nature, program risk assessment is a subjective process. Finally, even though TRACE has helped manage R&D cost, it has not eliminated cost growth.

The TRACE techniques currently used to develop R&D estimates can be used to develop production estimates as well. There are many similarities in the two areas. The uncertainties are just of a different nature. But a different perspective of initial production uncertainty was taken to improve upon the techniques.

A recognition that past production problems represent future production risk areas suggested an empirically developed risk structure which specifically addresses initial production risk. The risk structure evolved such that it captured and isolated fundamental production uncertainties, maintained as much independence as practical among the individual risk categories, and captured the synergism of the BCE investment cost elements. The Production Risk Assessing Methodology (PRAM) was developed by combining this risk structure with conventional cost estimating techniques to quantify initial production risks into a dollar estimate called Production Risk Assessing Cost Estimate (PRACE). The PRACE complements and improves upon the BCE by including consideration for those production risks not addressed in the BCE.

The PRACE concept can reduce production risk and cost growth. Use of PRACE funds will help reduce the number of program disruptions caused by funding shortages just as TRACE has done for R&D. It will also assist the PMO in planning for the transition and providing more realistic production cost estimates. PRACE, in conjunction with ongoing Army initiatives, will improve the acquisition process.

B. RECOMMENDATIONS.

The PRAM has the potential to assist in analyzing initial production risk and incorporating risk funds into the BCE. Accordingly, the following recommendations are made:

1. The PRAM should be evaluated by being applied to those Army systems recently entering production. The appropriate PMO's should be requested to exercise the PRAM by reconstructing their programs to the time period roughly two years prior to their Milestone III. The PRACE's produced by the exercises should then be compared to the current system

cost status for comparability. These exercises will serve to test and evaluate the methodology but primarily will provide a data base of recent experience with production problems within the PRAM framework. This data base will be useful in preparing future PRACE's. (Note Implementation: this is being accomplished).

2. PRAM should also be exercised by a HQ DARCOM cost team on a system(s) other than the above SAR systems to provide an independent acceptance test. The test system(s) must have adequate data to reconstruct the time period from roughly two years prior to Milestone III through at least three years of production. (Note Implementation: this is complete).

3. Assuming PRAM acceptance, it should be implemented within the Army through the issuance of a Letter of Instruction (LOI) similar to the TRACE LOI. The following implementation guidelines are suggested.

a. A PRACE should be developed at least three times during the transition period using the PRAM. The first exercise should take place roughly two years prior to Milestone III to insure the PRACE can be programmed for the early production years. Likewise, the second exercise, which becomes an update of the first, should take place a year or so before Milestone III to meet budget requirements. The third PRAM exercise should be part of the submission to ASARC/DSARC III to assist in their production decision.

b. The PRACE should be presented as part of the Investment Cost documentation for the BCE in cost element 2.11, "OTHER." The PRAM Summary and supporting rationale and calculations should be available for review.

c. The PRAM exercise should be a team effort, independent from the PMO with at least three team members. Suggested team members are one cost analyst from HQ DARCOM and one production engineer and one cost analyst from the appropriate MSC. PMO personnel should be relied upon to

provide information and to assist where needed in the analysis. It may be feasible to align the PRAM analysis with the PRR's, since all are concerned with production risk and cost.

d. The PRACE should be administered within the Army just as TRACE for R&D currently is. Funds approved for the PRACE should be held by ODCSRDA until justified for release by a PMO. Over time, a data base of PRACE justifications and experience will develop that can be used to determine and refine the PRACE's for future systems.

e. PRACE submissions should be mandatory for Army major weapon systems. Since it has been shown that most initial production problems and cost growth have surfaced within the first three years of production, PRACE funds should be available primarily for the first three years of production with some exceptions allowed where there is a low rate initial production.

4. PRACE concepts and methodologies should be added to the curriculum of appropriate courses at the Army Logistics Management Center and the Defense Systems Management College. A short, intensive seminar should be developed to train those analysts who will or may develop a PRACE.

5. A follow-on study should be initiated to develop early indicators of production cost growth that can be used to improve the PRACE. Some specific areas that appear to have good potential are as follows:

a. The relationship of cost growth to PEP funds as a percentage of RDT&E funds should be investigated.

b. The relationship of long leadtime item experience (including initial production facilities) to production cost growth may prove useful as an early indicator.

c. Staffing patterns within PMO regarding production engineering and management may explain a portion of the cost growth.

d. The relationship of major design problems to production problems in that design area may provide an early indicator of potential cost growth.

e. Finally, the pattern and amount of cost growth experienced by a system during FSED may be a useful indicator of production cost growth.

(Note Implementation; this is complete).

C. IMPLEMENTATION.

Between the time the draft report was prepared and the final report was published, recommendations 2 and 5 were implemented and implementation began on recommendation 1. Also, the PRAM was incorporated, with some modifications, into an approved DARCOM methodology titled Total Risk Assessment Cost Estimating for Production (TRACE/P). TRACE/P is being applied where appropriate to develop cost estimates which include consideration for initial production risk.

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techniques can be used to address initial production risks, the Production Risk Assessing Methodology (PRAM) offers an improvement. It combines an empirically developed risk structure with conventional cost estimating techniques to quantify initial production risks into a dollar estimate which complements the Baseline Cost Estimate. Using the PRAM production risk and cost growth can be reduced. (Note: PRAM, with some modifications, has been incorporated into a DARCOM approved methodology titled Total Risk Assessment Cost Estimating for Production (TRACE/P)).

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